Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Environmental Sciences 9 (2011) 201 – 208
Procedia Environmental Sciences

Ecological engineering: from concepts to applications

Managing the downstream pollution problems and poverty reduction in the tropical developing world: relying on the integration of nature's library, traditional knowledge and ecological sanitation

B.B. Jana[a], *

[a]International Centre for Ecological Engineering, University of Kalyani, Kalyani – 741 235, West Bengal, India

Elsevier use only: Received date here; revised date here; accepted date here

Abstract

The ecosystem management technologies are low cost, environment-friendly and effective, and are based on the interdependence and symbiotic relationships amongst some components of the ecosystem such as microalgae, probiotics, floating, rooted and marginal weeds, artificial islands, herbivorous fishes, mussels, benthic animals, etc. Due to relatively high toxic tolerance and rapid turnover of high organic loading, the so-called living machines develop self design and regulation in functional processes providing reclamation and ecosystem services. Other innovative methods are bottom raking with benthivorous animals, integrated wastewater management using solar-energy driven biological process like aquaculture and hydroponics. Right selection of species from nature's library, traditional knowledge, wise planning, innovative application and patience to natural functioning of ecosystems are the main attributes of the begin - of - the- pipe approach. It is unique for solving much of the environmental problems related with industrial development. It is now realized that the society may benefit more from the integration of ecological engineering and ecological sanitation. As a sustainable source of materials and energy, ecological sanitation can be profitably integrated with ecological engineering in terms of ecosystem services to the society. Human urine or feces obtained from source separated dry toilet can be profitably recycled into the production of vegetables in agriculture, or algal biomass or fish biomass in aquaculture and, hence, reap double benefits by protecting the environment from excreta-related pollution and by promoting the philosophy of recycling wastes into wealth. The present paper examines the state-of-the-art of the low-cost, nature-based reclamation strategies and economic use of reclaimed wastewater and the integration of ecological engineering and ecological sanitation.

Selection and/or peer-review under responsibility of Laboratory "Biochemistry and ecology of continental environments

Keywords: ecosystem management; eco-toilet; living machine; wastewater-aquaculture; wastewater-reclamation

1. Introduction

The world is passing through a state of serious crunch of resources, both non-renewable and renewable. Water constitutes the major renewable resource. Freshwater available on earth is 2.5 % of the total 1 386 million cubic

* Corresponding author.
E-mail address: bbj_icee@yahoo.co.in/bbj@cal2.vsnl.net.in.

Selection and/or peer-review under responsibility of Laboratory "Biochemistry and ecology of continental environments
doi:10.1016/j.proenv.2011.11.031

kilolitres and only one-third of this small quantity is available for human use. Heavy demand of water has resulted in a three-fold increase in the withdrawal of ground water during the last five decades and is projected to increase further by 2025. The recent climate change has further aggravated the scenario of water crisis having serious impact on surface and ground water resources. In Asia with the highest human pressure on land, per capita fresh and clean water supply is the lowest in the world. It becomes, therefore, urgent to conserve 20 – 60 % of fresh surface water supplies. The available water conservation and reclamation strategies of water resources are: rain water harvesting, advanced irrigation in agricultural crops, minimizing water loss, public participation programme, etc.

Right selection of species from nature's library using traditional knowledge, wise planning, innovative application and patience to natural functioning of ecosystem are the main attributes of the begin - of – the - pipe approach. It is mimicked with nature to solve the environmental problems using constructed wetlands, fish-biofilter integrated biosystem, compatible living machines in the biosystem, green roofs for improving living conditions in cities, source separation and composting toilets, eco-houses and eco-villages, and eco-san, eco-engineering integration and many others aimed at the welfare of human society.

2. The ecological engineering approach

2.1. Innovative methods

Reclamation of eutrophic waters and wastewaters has become a global agendum during recent years. Though there are about twenty different techniques available for restoring eutrophic waters and wastewaters [1], such restoration techniques has proved to be extremely difficult in many cases [2], primarily due to the fact that the recovery potential of any damaged ecosystems depends on the extent of mode of operation of the stressor. The design of sustainable ecosystem is based on the premises of interdependence and symbiotic relationships amongst the component members of the ecosystem such as bacteria, microalgae, floating, rooted and marginal weeds, fishes, mussels, annelids, etc. As a consequence, it has been greatly emphasized for wastewater reclamation and water conservation in developing countries.

2.2. The working principle

Restoration and reclamation of contaminated lakes and wetlands are done using the theory of a specially designed system of production process in which the principles of the species symbiosis and the cycling and regeneration of substances in an ecological system are applied. In practice, ecological engineering is mimicked with nature to solve the environmental problems for the benefit of human society. Due to relatively high toxic tolerance and rapid turnover of high organic loading the so called living machines develop self design and regulation in functional process that led to system reclamation and ecosystem services.

2.3. The fundamentals of ecological engineering

The fundamental principles of ecological engineering are holism, harmony, self resiliency, regeneration and circulation and multilayer and multiuse system [3]. The holistic effect is larger than that of the simple sum of all the elements comprising the ecosystem. As a result, holistic approach is much more meaningful and significant than at the species level. The ecosystems are cybernetic in nature, maintaining harmony which not only maximizes substance production, spatial and trophic niche and economy, but also causes less environmental pollution [4]. Self resiliency enables the ecosystem to recover when systems are disturbed by a perturbation [5]. Self-resiliency includes self regulation, self organization, self regeneration, self reproduction, self purification, etc.

Regeneration and circulation of substances is another crucial factor for survival and development of natural ecosystems. According to second law of thermodynamics, any product in the world will inevitably be turned into wastes at the end; yet every waste is bound to be a resource [4]. When a resource is not used, it becomes a source of waste, even pollution. It is rather a question of management that prevents pollution as conversion of wastes into wealth is basically done by the circulation between wastes and products through microbial biogeochemical cycle.

2.4. Relevance in the developing countries

In the developing countries, rapid pace of industrialization has caused replacement of natural ecosystems with the unidirectional goal of production for a short term and local scale benefits. Due to its low cost, eco friendly, nature based and ease of procurement and maintenance, ecological engineering has emerged as an important tool for the mutual benefit of human being and nature in the developing countries where it can speed up their economic and ecological development and march towards sustainable wealth, health and faith.

2.5. Restoration of water bodies: a holistic view

Uncontrolled input of domestic wastewater, intensive fertilizer use, agricultural run off containing excess amount of nitrogen and phosphorous have resulted in eutrophication with massive algal blooms in a large number of inland water bodies. As a result, vast areas of surface waters in the tropical countries have become unsuitable for fish farming or for other economic driven activities. The low cost reclamation strategies (Fig.1) are highly imperative for conservation of water as well as to boost the economy of the rural people. Conservation of water resources, aquatic biodiversity, production of zero or no wastes from industries and cost effective aqua-based production are in the global agenda for the current millennium.

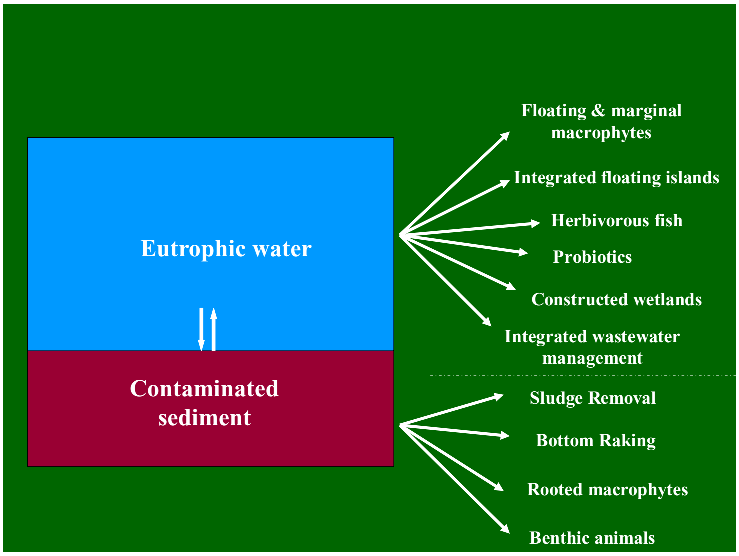

Fig. 1. Low cost reclamation strategies

2.6. Conservation of wastewater through aquaculture

Wastewater-fed aquaculture ponds provide an economically viable source of high protein through recycling of organic residues in the eco-friendly balanced system and thus maximizing waste recycling and reuse, and converting wastes into wealth. The concept of wastewater aquaculture is that the organic wastes are recycled into fish biomass since fish is the cheapest animal product when grown on wastewater. Moreover, fish grows very fast in tropical wastewater fed ponds and thus replaces the expensive supplementary diet and conventional chemical fertilizers. The production cost of fish is greatly reduced, which is the main interest of poor farmers. A large number of people subsist on this novel method of aquaculture.

The waste disposal practice is based on the philosophy that the ‘solution to pollution is dilution’. Considerable reduction of organic and BOD loads of sewage is a prerequisite for its use in aquaculture. In general, there was about 30 % reduction of the BOD load of raw domestic sewage (120 and 400 mg 1^{-1}) by the primary treatment of sedimentation.

Because of the presence of certain obnoxious gases, like unionized ammonia and hydrogen sulphide, in the treated effluents even after the reduction of BOD load, the treated effluents remain anaerobic and are not suitable for a direct use in fish farming. As a result, dilution with freshwater (1:1 to 1:4) or proper loading of sewage provides congenial environment and aerobic condition essential for fish culture. As a rule, organic and bacterial loads are substantially reduced in the sewage treatment systems for effective use of sewage in aquaculture.

The wastewater aquaculture has a unique capacity for reclamation of wastewater through nutrient recovery. At a conservative estimate, 800 mg of sewage can yield an annual out turn of 60,000 tons of NPK fertilizers.

Judicious selection of fish species is another key factor for effective utilization of sewage in fish culture. Omnivorous and bottom grazing fishes directly consume the organic detritus of sewage fed ponds and thereby help to keep the pond bottom aerobic through bioturbation activity. The suitable species for culture are: Indian carp, Israeli carp, silver carp, bighead carp, grass carp, common carp, hybrid buffalo, catfish, largemouth bass, tilapia, freshwater prawn, etc.

In a model town Kalyani, partially treated sewage effluents are flown along a gradient through a series of anaerobic, facultative and fish growing ponds, and finally effluents are discharged into the river canal. An average retention time of 5 days was maintained throughout, and a BOD_5 level of 10-20 mg 1^{-1} of pond water should be continuously maintained for better fish growth. It was observed that the facultative ponds were the most dynamic accounting 22- 69 % of the total reclamation of the waste stabilization ponds. The next sub system of fish growing ponds was responsible for converting organic wastes into fish biomass through grazing-detritus-food chain mechanism using the ecological principle of recycling through microbial biogeochemical nutrient cycle and grazing detritus food web.

2.7. Wastewater reclamation using macrophytes

Macrophytes are often described as scavengers of contaminants in surface waters as they have the capacity to accumulate toxic metals and heavy metals like Zn, Pb, Cu, Mg, Mn, Ag, As, Cd, Co, Cr, Ni, Sn, etc. They are also effective in removing pollutants like pesticides, insecticides, petroleum hydrocarbons, fluoride, hydrogen sulphide and volatile fatty acids [6]. Further, the macrophyte based wastewater treatment system caused significant reduction in fecal coliforms and other pathogens [7].

It has been demonstrated that floating macrophytes remove nutrients from the water phase, whereas emergent macrophytes met up their P requirements exclusively from sediments. Rooted submersed macrophytes absorb most of the P from the interstitial water of the sediments and also from the surrounding water. Therefore, integration of floating, rooted and emergent macrophytes (Fig. 2) is of great use for conservation reclamation for aquaculture.

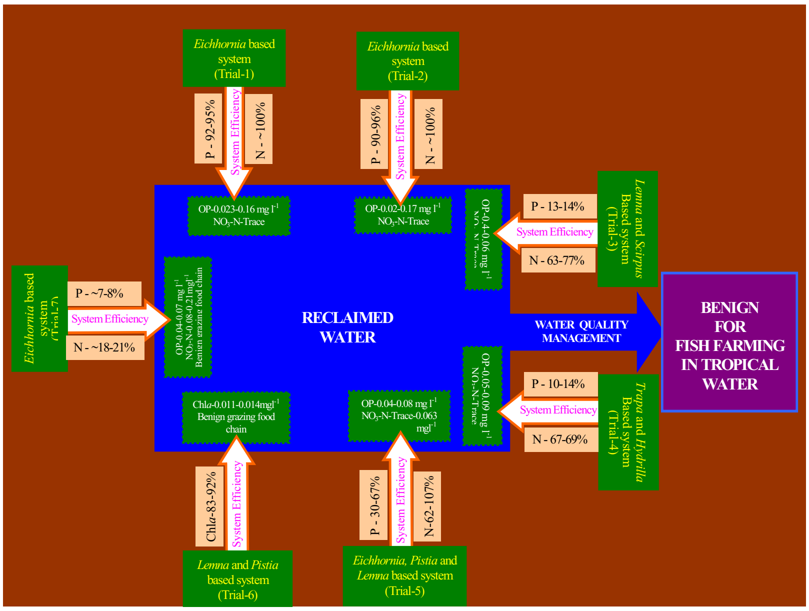

Fig. 2. Beneficial effects of macrophytic reclamation and possible use of reclaimed water for fish farming

2.8. Control of algal bloom using fishes

A common symptom of lake eutrophication is the appearance of algal blooms caused by cyanobacterial (blue-green) species such as *Microcystis, Anabaena, Oscillatoria, Nodularia, Nostoc*, etc. [8]. Though some blue-greens are known to be toxic due to their secretion of more than sixty toxins grouped under neurotoxins, hepatotoxins, cytotoxins, contact irritants and gastrointestinal toxins, it cannot be considered as a general rule for all the blue-green species. The non-toxic strains of cyanobacterial blooms comprise an important source of the diet of a number of cyprinid and cichlid fishes [9] as they are reported to contain more than 50 % proteins [10]. Among the cyprinids, silver carp has been demonstrated to be the most promising candidate and, therefore, has been extensively used to control algal blooms in many eutrophic lakes and reservoirs; that may replace the traditional use of harmful chemical agents.

The results of the study show that silver carp, big head and tilapia were highly efficient in controlling permanent *Microcystis* bloom (60- 90 %) in eutrophic lake [11]. *Microcystis* grazing by silver carp, however, varied with the age of fishes because the 2 months-old silver carp had negative selectivity for *Microcystis*, whereas 6 or 12 months-old silver carp consumed *Microcystis* as usual. The potentials for enrichment among the fishes were in the order: tilapia > bighead > silver carp. Tilapia may be used for short term and in small ponds only to avoid ichthyo-eutrophication. However, long-term studies in tropical lakes are necessary to examine the ecological consequences of these fish introductions into *Microcystis* bloom infested water bodies.

2.9. Reclamation of cadmium intoxicated waters by freshwater bivalves

The rapid pace of industrialization resulted in contamination of many inland water bodies including river systems in India. Cadmium is one of the most toxic heavy metal to human being causing damage to lungs, kidneys, etc. Appreciation of unique ability of certain plants and animals to accumulate trace metals above ambient water concentrations has led to use some molluscs as biofilters as they are the consumers of first order in the trophic food chain and therefore can accumulate high amount of cadmium without any obvious sign of distress or visible physiological effects Because of detoxifying and depuration mechanisms, these animals are capable of effective depuration in clean water, and the same animal may be used again as a biofilter. Depuration rate in some mussels was an exponential function of exposure time [12].

Freshwater bivalve is one of the most suitable candidates for the removal of cadmium from intoxicated environments. Freshwater bivalve *Lamellidens marginalis* collected from pollution-free natural ponds, were sorted into three size groups (small, medium and large) and were held in cages at three different sites along a cadmium concentration gradient. Freshwater bivalve *Lamellidens marginalis* accumulated as high as 165, 220 and 445 $\mu g\ g^{-1}$ dw of cadmium in their tissue when exposed for 6 weeks to ambient cadmium concentration of 10, 20, 30 $mg\ l^{-1}$, respectively [12]. Small animals are more sensitive to cadmium accumulation than large ones. Cadmium depuration in *Lamellidens* can be induced maximally by placing the animal in cleanwater-*Eicchornia* system compared to cleanwater, or cleanwater- EDTA treatments.

2.10. Design of sustainable ecosystem

Design is the key factor of ecological engineering that uses traditional knowledge of biodiversity and, therefore, poised to be low cost and eco-friendly tool for the mutual benefit of industry and nature and benefits are immense (Fig. 3). Ecosystem development using different macrophytes, bivalves, herbivorous and benthivorous fish may be employed as biofilter agents that would provide better ecosystem service to the society.

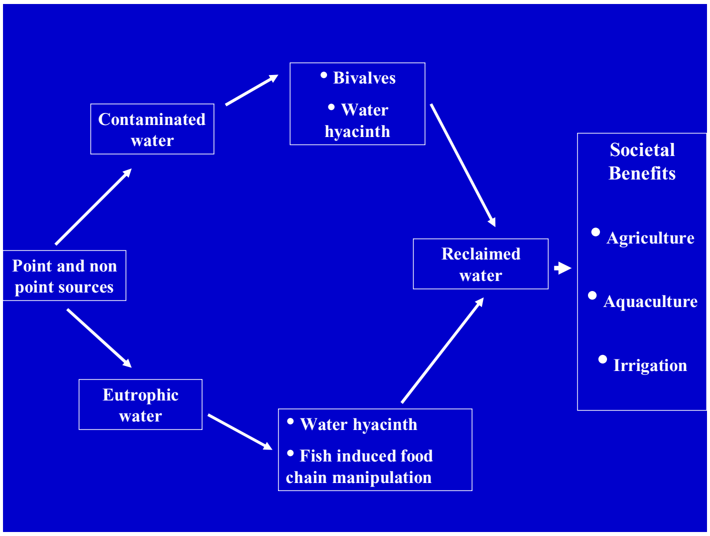

Fig. 3. Benefits of water reclamation

3. Searching the nutrient source for ecosystem function

Search for the potential nutrient source for the ecosystem to function has led to develop a close link between ecological sanitation and ecological engineering for much of the benefits in the society. As a sustainable source of materials and energy, ecological sanitation can be profitably integrated with ecological engineering in terms of ecosystem service to the society.

Though the ecological sanitation has been primarily developed to provide basic sanitation needs to a large section of poor people in the world (as 2.4 billion lack access to basic sanitation) as well as to protect environmental contamination from human wastes, it may be profitably linked to close the loop between the human wastes and cash crop production through recycling. This essentially integrates certain principles of ecological sanitation and ecological engineering for sustainable development of both. In India, nearly 60 % of the population have no access to proper sanitation, and, therefore, are forced to develop open defecation practice causing contamination of water bodies.

In practice, human urine or feces obtained from source separated dry toilet are profitably recycled for the production of vegetables in agriculture or algal biomass or fish biomass in aquaculture. This provides double benefits to the society in terms of protecting the environment from open defecation and pollution and promoting the philosophy of recycling waste into wealth, in the form of human urine into bio-wealth. It is almost analogous to the second law of thermodynamics at the energy level, where highly concentrated state is toxic and transformed into more and more diluted form creating the benign environment for biological production. The rationale of using human urine in biological production is based on the premises that each person, on an average, contributes about 4.6 kg of nitrogen, 0.4 kg of phosphorus and 11 kg of potassium each year besides the growth-promoting substances in the form of amino acid, glucose, vitamins.

The experimental results carried out so far suggest that human urine can be used as potential nutrient source for the production of phytoplankton, zooplankton and fish. Comparison of the fertilizer value of fresh and stored human urine revealed that phytoplankton growth and primary production were significantly higher in the stored urine-fed treatment than in fresh urine due to increased level of nutrient load in the former than in later. As the primary production of phytoplankton was the direct function of the concentrations of phosphate, nitrate or the sum total of three species of inorganic nitrogen in different urine-fed treatments, this suggests that these nutrients of the urine are very important for the production of fish food.

Further, human urine was an important input fertilizer for the production of zooplankton and fish. Neonates of zooplankton *Moina micrura* held in the treatment with human urine started reproduction at least 4 days earlier than with the other solid waste tested. Total number of *Moina* enumerated in the culture tank was maximum in case of human urine treatment. The relationship between the total offspring production per female per life span and nitrogen content of water in different treatments implied that human urine was an excellent liquid waste that can be used for mass production of zooplankton required for larval and post larval rearing of commercial fishes.

The results of comparative evaluation of the fertilizer values of human urine and some common organic wastes were very convincing. It was shown that rohu was conspicuous by its maximum growth in urine-fed treatment (HU) compared to cattle dung (CD) even though the total yield of fish was maximum in the latter than in former. The total yield of fish in the iso- nitrogenous and iso- phosphorus treatments ranked second and third respectively (Fig. 4). This suggests that mixed treatment charged with urine might be suitable for the culture of carps and especially rohu in all the urine-fed treatments.

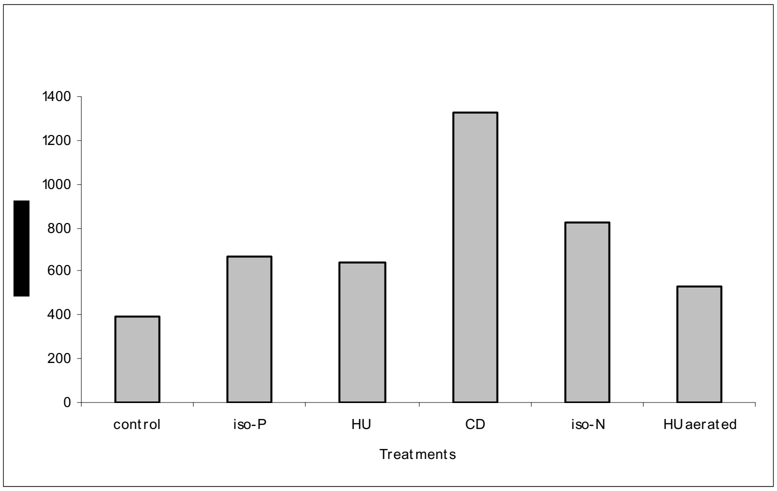

Fig. 4. Variability of total fish yield in different treatments employed

As the results of the present bacteriological study of urine-fed aquaculture showed quite low contamination load of *E. coli* which was within the limit for wastewater fed aquaculture, urine may be recommended as a liquid fertilizer for fish culture.

4. The need for integration

It is highly imperative to establish a close link between the ecological engineering and ecological sanitation. The functioning and the maintenance of sustainable ecosystem are dependent upon the nutrients that may be obtained from the source separated composting toilet or ecological sanitation developed to provide basic sanitation facilities and dignity to large section of poor people in the developing world. The technological input from ecological engineering would provide the base for well thought ecosystem design using ecosan as nutrient source (Fig. 5). Therefore, the integration of ecosan and eco engineering has been thought to provide considerable benefits to the society.

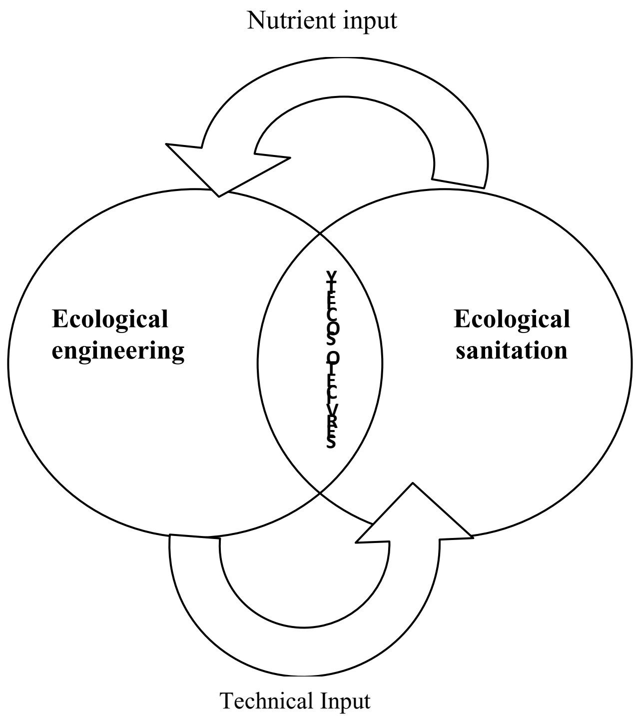

Fig. 5. Interdependency of ecological engineering and ecological sanitation

References

[1] F.B. Welch, Eutrophication, In: Ecological effects of wastewater, applied limnology and pollutant effects, Chapman and Hall, London, UK, 1996.
[2] G. Van Straten, The predicting power of models for eutrophication, In: Eutrophication: Research and Application to Water Supply, D.W. Sutcliffe, and J.G. Jones (Eds.), Freshwater Biological Association, Ambleside and International Water Supply Association, London, UK, (1992)44.
[3] J. Yan, R. Wang, and M. Wang, Ecol. Eng., 10(1998)191.
[4] S. Ma, and J. Yan, Ecological Engineering for treatment and utilization of wastewater, In: Ecological Engineering: An introduction to Ecotechnology, W.J. Mitsch, and S.E. Jorgenssen (Eds.), Wiley, New York, USA, 1989.
[5] W.J. Mitsch, Ecological engineering: a new paradigm for engineers and ecologists, In: Engineering within Ecological Constraints, P.C. Schulze (Ed.), National Academy Press, Washington DC, USA, (1996)111.
[6] K.S. Low, C.K. Lee, and C.H. Tai, J. Environ. Sci. Health Part A: Environ. Sci. Eng., A29(1994)171.
[7] Z. Wu, X. Yicheng, D. Jiaqi, K. Qijun, Z. Facui, and C. Xitao, Water Sci. Technol., 27(1993)97.
[8] G.A. Codd, Ecol. Eng., 16(2000)51.
[9] P. Spataru, and M. Gophen, Hydrobiologia, 120(1985)53.
[10] F.C. DeMoor, and W.E. Scott, Digestion of *Microcystis aeruginosa* by *Oreochromis mossambics*, Journal of Limnological Society of Southern Africa, 11(1985)14.
[11] S. Datta-Saha, and B.B. Jana, J. Fish Biol., 53(1998)12.
[12] B.B. Jana, and S. Das, Ecol. Eng., 8(1997)179.